use of Wien's displacement law $\lambda_{max} \propto \frac{1}{T}$ to estimate the peak surface temperature (of a star) — M0.4 HSW5

luminosity L of a star; Stefan's law $L = 4\pi r^2 \sigma T^4$ where σ is the Stefan constant — Learners will also require knowledge of 4.4.1

use of Wien's displacement law and Stefan's law to estimate the radius of a star. — M0.4 HSW5

(6) M - Apply Wein's displacement law to estimate peak surface temperature
(7) S - Apply Stephan's law to find the luminosity of a star
(8) C - Use both laws to find the radius of a star

Stellar luminosity

STARTER: Try 2017 question on stars / analysis star light

SA

Extension: WWW/EBI SR

WWW/EBI

SR $E = hf = \frac{hc}{\lambda}$

Question		Answer	Marks	Guidance
(a)	(i)	electron bound to nucleus / represents energy electron must gain to leave the atom / total energy of electron in atom is less than that of a free electron	B1	Allow ionisation level defined as zero as AW for 'represents electron must gain energy to leave atom / move up energy level' Allow potentials for attractive forces are negative.
	(ii)1	energy = 2.55 (eV)	B1	Ignore sign
	(ii)2	energy = 2.55 × 1.60 × 10⁻¹⁹ (J); $\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.55\times1.60\times10^{-19}}$ (Allow any subject); wavelength = 4.9 × 10⁻⁷ (m); wavelength = 490 (nm)	C1 C1 A1	Possible ECF from (ii)1; Note: wavelength = 488 (nm) to 3 sf
(b)	(i)	Electron(s) makes a transition to a lower (energy) level / loses energy and emitting a photon(s) / EM radiation	B1	
	(ii)	Reduce grating separation / increase distance between grating and screen	B1	Allow 'use finer grating' or 'use grating with more lines mm⁻¹' Not 'smaller slit size'
	(iii)	wavelength (of peak) = 661.5 nm; v = 3.0 × 10⁸ × (661.5 − 656.3) / 656.3; recession velocity = 2.4 × 10⁶ (m s⁻¹)	C1 C1 A1	Allow: between 661 and 662 nm; Note: check divided by 656.3 nm; Range of acceptable answers: 2.1(5)-2.6(1) × 10⁶
	(iv)	(Relative) abundance of hydrogen (AW)	B1	Allow 'Hydrogen commonly found in stars' (AW)
(c)		Less intense; Galaxy is moving faster and therefore greater / longer wavelength (AW); Periodic shift in wavelength (if plane of orbit is in line of sight) (ORA)	B1 B1 B1	Allow 'greater red shift' / 'greater Doppler shift' / 'to the right' for longer wavelength; Allow argument referring to splitting of line because of relative velocities of two component stars. Not idea of blue shift.
			Total 14	

Sep 29-15:54

Modelling 2017

21 (a) Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms. The energy levels are labelled **A**, **B**, **C** and **D**.

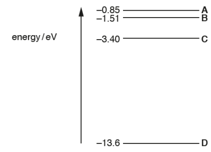

Fig. 21.1 (not to scale)

(i) Explain why the energy levels are negative.

....

.... [1]

(ii) An electron makes a transition (jump) from level **C** to level **A**.

1 Calculate the energy gained by this electron.

energy = 2.55 eV [1]

2 Calculate the wavelength in nm of the photon absorbed by this electron.

$= 2.55 \times 1.6\times10^{-19}$ J

$\frac{hc}{\lambda} = E$

$\lambda =$

wavelength = 488 nm nm [3]

Feb 5-14:09

(b) Light from a distant galaxy is passed through a diffraction grating. Fig. 21.2 shows the part of the spectrum of light that shows a strong hydrogen-alpha emission line.

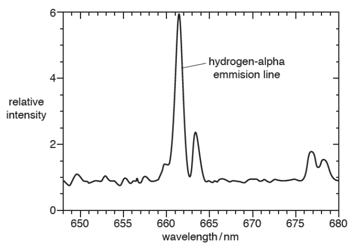

Fig. 21.2

(i) State how an emission line is produced.

....

.... [1]

(ii) State an adjustment that could be made to the experimental arrangement that would space the emission lines more widely.

....

.... [1]

(iii) In the laboratory, the wavelength of the hydrogen-alpha emission line is 656.3 nm. Use Fig. 21.2 to determine the recession velocity of the galaxy.

Feb 5-14:09

(6) M - Apply Wein's displacement law to estimate peak surface temperature
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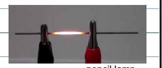
(8) C - Use both laws to find the radius of a star

Stellar luminosity

Discuss, what happens when you heat a material - though a range of temperatures?



pencil lamp

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Wein's displacement law

All objects emit EM radiation (above 0K)

Stars can be modelled as a perfect black body. Define a 'black body'

Activity: Describe the features of this intensity v wavelength of EM radiation graph for a black body at 6000K

Ex: How might the graph change if the black body was heated/cooled to a)9000K b)4000K

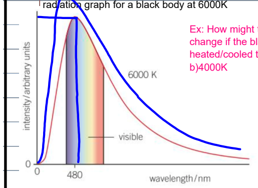

Figure 2 *The intensity–wavelength graph for a black body at a temperature of 6000 K*

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(6) M - Apply Wein's displacement law to estimate peak surface temperature
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Wein's displacement law

Wein's displacement law states that the absolute temperature of a black body is inversely proportional to the peak wavelengths.

$\lambda \propto \frac{1}{T}$

Therefore: λT = constant

Wein's constant = 2.90x10-3mK

Ex: What is the unit of Wein's constant

Ex: How does this law help astrophysicists?

Ex: How does this law help astrophysicists?

They can determine the temperature of a star by the EM radiation they emit.

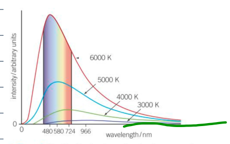

Figure 3 *The distribution of wavelengths changes as the temperature of the black body emitter changes*

Activity: Use the law to estimate the missing information below.

Ex: Use the law to estimate the missing information below.

Object	λ_{max} / m	T / K
Healthy human	9.4×10^{-6}	310
Wood fire	1.9×10^{-6}	1500
Betelgeuse (red supergiant)	8.5×10^{-7}	3400
Sun	5.0×10^{-7}	5800
Sirius B (white dwarf)	1.2×10^{-7}	25 000

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Stephan's law 1m 10W

Total power radiated per unit surface area of black body is diectly proportional to the 4th power of the absolute temperature.

Ex: Derive the formula. (lower case sigma is 'stephan's constant)

$$L = 4\pi r^2 \sigma T^4$$

Quantity /unit

- L- luminosity / W
- r- radius / m
- σ- Stephan constant. / $Wm^{-2}K^{-4}$
- T- Absolute temp /K.

give example from booklet

Activity: Try the summary questions 4 and 5

4 Using Stefan's law, compare the luminosity of a star with another that has:
a double the surface temperature and the same radius;
b double the radius and half the surface temperature;
c half the mass, the same density, and three times the surface temperature. (6 marks)

5 The Sun has a radius of approximately 700 000 km and a surface temperature of 5800 K. Calculate the energy radiated by the Sun during one year. (3 marks)

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Finding the radius of a star (could LO)

Worked example: Radius of a star

The peak wavelength of radiation emitted by our Sun is about 500 nm, its surface temperature is 5800 K, and its luminosity is 3.85×10^{26} W. The peak wavelength emitted by a nearby star with a luminosity 10 times that of our Sun is 310 nm. Show that the radius of this star is approximately 840 000 km.

Step 1: To determine the surface temperature of the star use Wien's displacement law.

$$\lambda_{max} T = \text{constant}$$

$$\underbrace{500 \times 10^{-9} \times 5800}_{\text{Sun}} = \underbrace{310 \times 10^{-9} \times T_{Star}}_{\text{Star}}$$

Therefore

$$T_{Star} = \frac{500 \times 10^{-9} \times 5800}{310 \times 10^{-9}} = 9355\,\text{K}$$

Step 2: Use Stefan's law to determine the radius of the star.

$L = 4\pi r^2 \sigma T^4$, therefore $r = \sqrt{\frac{L}{4\pi\sigma T^4}}$

The luminosity L of the star is $10 \times 3.85 \times 10^{26}$ W

$$r = \sqrt{\frac{10 \times 3.85 \times 10^{26}}{4\pi \times 5.67 \times 10^{-8} \times 9355^4}}$$

$r = 8.399... \times 10^8$ m = 840 000 km (2 s.f.)

Sep 29-15:54

(6) M - Apply Wein's displacement law to estimate peak surface temperature
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Finding the radius of a star (could LO)

6 The peak wavelength emitted by a distant star with a luminosity of 4.85×10^{31} W is measured as 305 nm using a diffraction grating. Calculate the radius of this star. (5 marks)

Ex:

3 Use these two relationships to find the requested value.
a A star emits light with a peak wavelength of 537 nm and has a luminosity of 2.64×10^{26} W. What is the star's radius?
(4 marks)
b A scientific model suggests a star with a radius of 6.26×10^9 m, that has a luminosity of 1.83×10^{29}. If these values are correct, what will the peak wavelength be?
(4 marks)

3 The first of these calculations follows the example closely. The second needs a slightly different approach.

a
$T = \frac{2.9 \times 10^{-3}}{\lambda_{max}}$
$= \frac{2.9 \times 10^{-3}}{537 \times 10^{-9}}$ (*1 mark*)
$= \left(\frac{2.9}{537}\right) \times 10^6$
$= 5400.3724$ K
$= 5400$ K (three significant figures) (*1 mark*)
$r^2 = \frac{L}{(4\pi\sigma T^4)}$
$r^2 = \frac{2.64 \times 10^{26}}{(4 \times \pi \times 5.67 \times 10^{-8} \times (5400.3724)^4)}$ (*1 mark*)
$r^2 = \frac{2.64 \times 10^{34}}{(4 \times \pi \times 5.67 \times 8.505\ 4018 \times 10^{14})}$
$r^2 = \frac{2.64 \times 10^{20}}{(4 \times \pi \times 5.67 \times 8.505\ 4018)}$
$r^2 = 4.356\ 283\ 841 \times 10^{17}$
$r = 660\ 021\ 502.8$ m
$= 6.60 \times 10^8$ m (three significant figures) (*1 mark*) (*4 marks*)

b
$L = 4\pi r^2 \sigma T^4$
$T^4 = \frac{L}{4\pi r^2 \sigma}$ (*1 mark*)
$T^4 = \frac{1.83 \times 10^{29}}{(4\pi \times (6.26 \times 10^9)^2 \times 5.67 \times 10^{-8})}$ (*1 mark*)
$T^4 = \frac{1.83 \times 10^{29}}{(4\pi \times 6.26^2 \times 5.67 \times 10^{10})}$
$T^4 = \frac{1.83 \times 10^{19}}{2792.1682}$
$T^4 = 6.554\ 0462 \times 10^{15}$
$T = 8997.6143$ K (*1 mark*)
$T = 9000$ K (three significant figures)
$\lambda_{max} = \frac{2.9 \times 10^{-3}}{T}$
$= \frac{2.9 \times 10^{-3}}{8997.6143}$
$= 3.223\ 0765 \times 10^{-7}$ m
$= 322$ nm (three significant figures) (*1 mark*) (*4 marks*)

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(6) M - Describe energy levels in isolated atoms
(7) S - Explain emission spectra in terms of transition of electrons between energy levels
(8) C - Explain how spectral lines can be used to identify elements within a star

Plenary circle

Simple key terms

Challenging key terms

Use 1-3 key terms to make a sentence that shows knowledge and understanding towards the HLOS

Sep 29-15:54

Feb 5-15:31